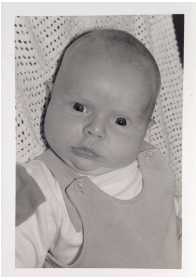
New results for VHEeP

Max-Planck-Institut für Physik, 2 June 2017

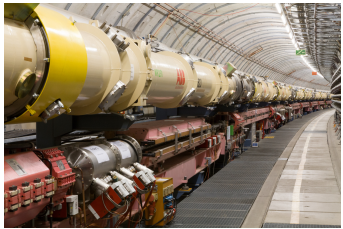
Fearghus Keeble, UCL

1992

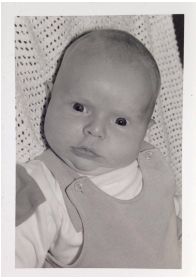
1992



Massive increase in the understanding of QCD



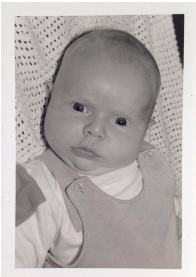
1992



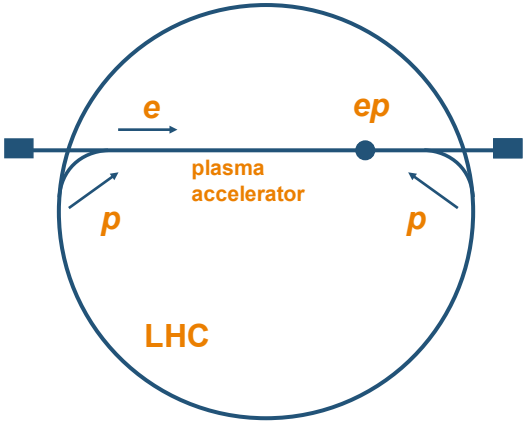
2007

Massive increase in the understanding of QCD

1992 2007

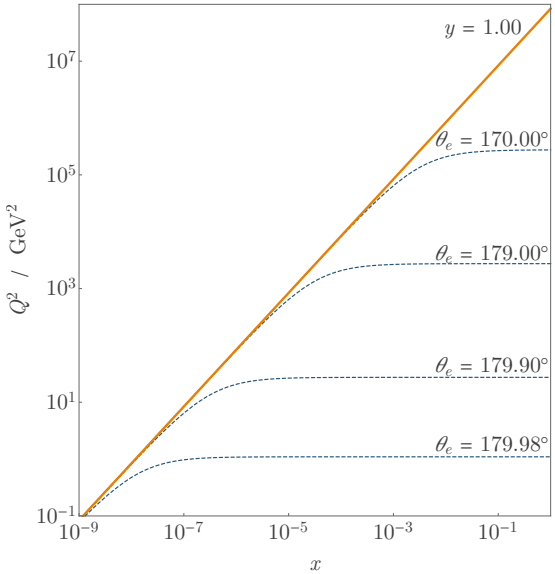


Massive increase in hair



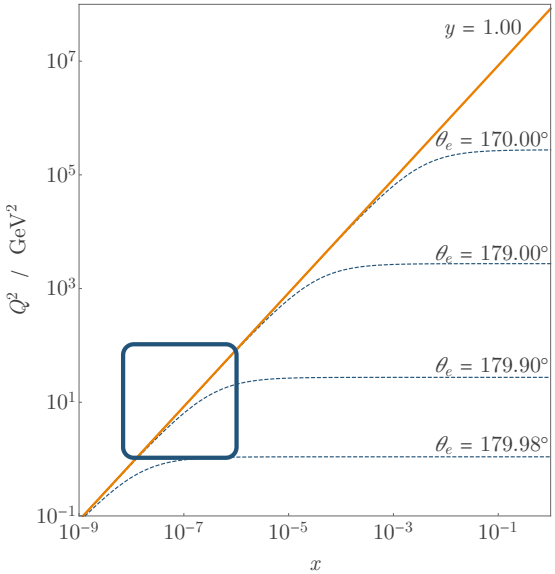
$$E_p = 7 \text{ TeV}$$
$$E_e = 3 \text{ TeV}$$
$$\sqrt{s} \simeq 9 \text{ TeV}$$

I will give an overview of the VHEeP kinematics as well as an update on some of the plots from Allen and Matthew's paper



$$Q^2(x,\,\theta_e) = sx \cdot \frac{E_e}{E_e + xE_p \tan^2(\theta_e/2)}$$

- Post-collision electrons in the region of interest will be collinear or near-collinear with the electron beam.



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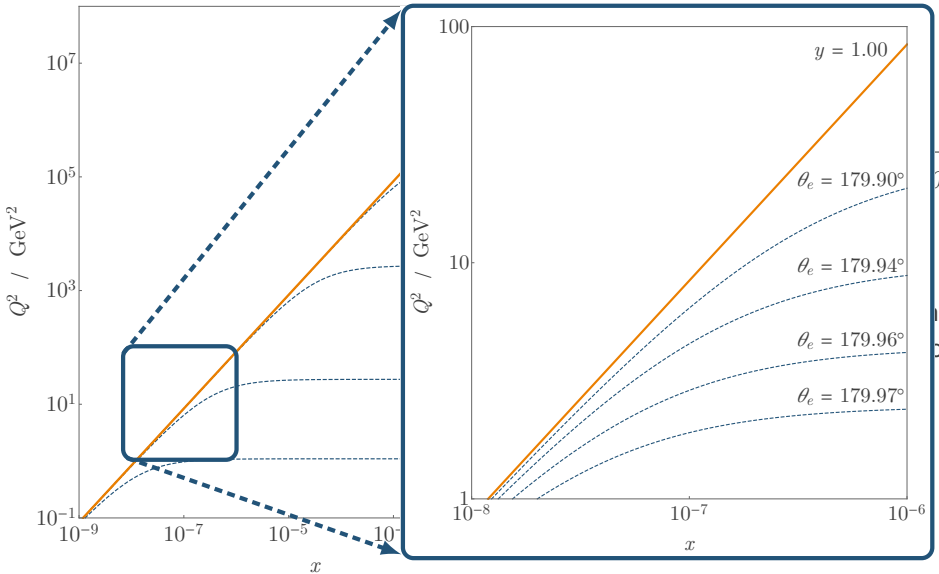

$$\frac{E_e}{xE_p \tan^2(\theta_e/2)}$$

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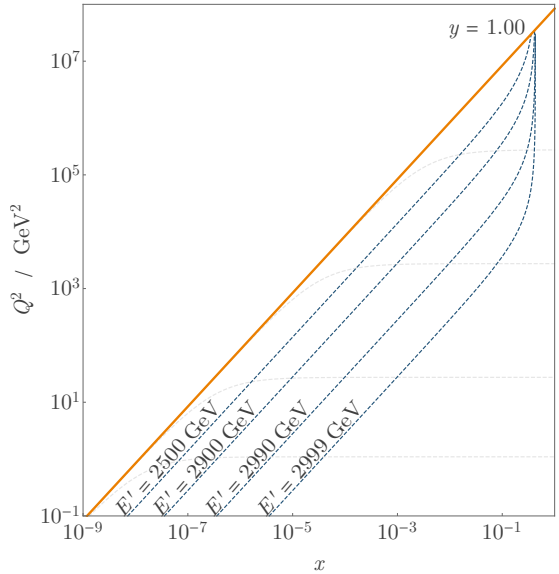
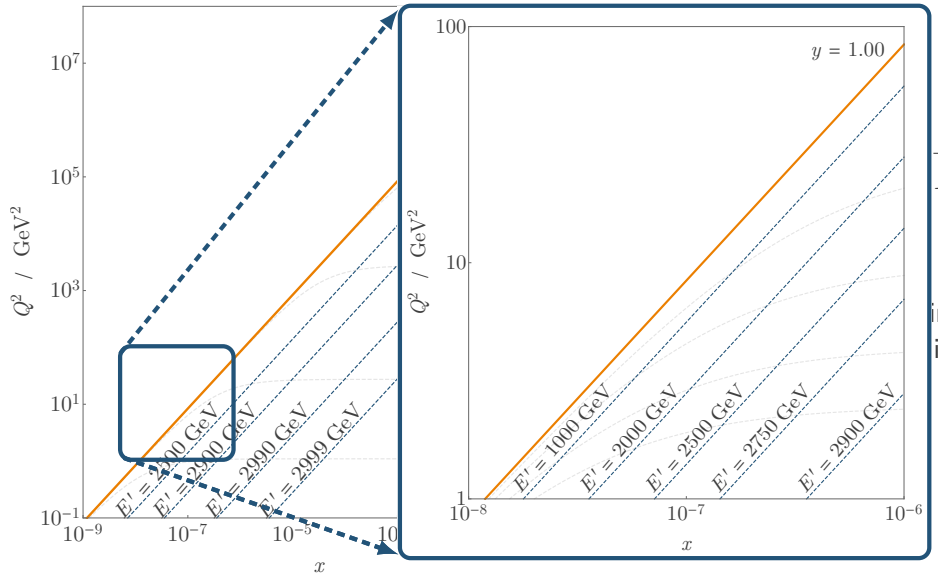


$$Q^2(x,\, E') = sx \cdot \frac{E_e - E'}{E_e - xE_p}$$

- Post-collision electrons in the region of interest can have very different energies to the beam.



$$\frac{E_e - E'}{E_e - xE_p}$$

in the region of
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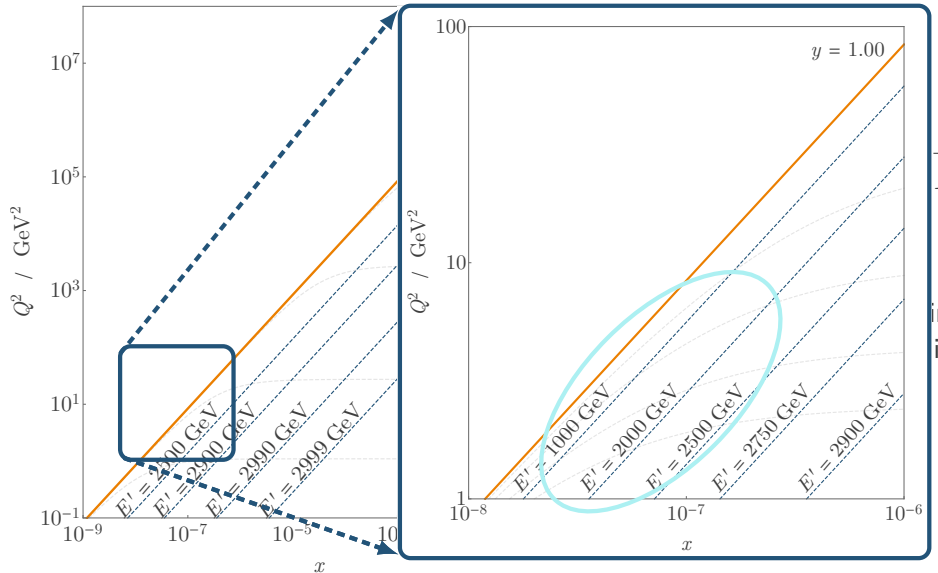

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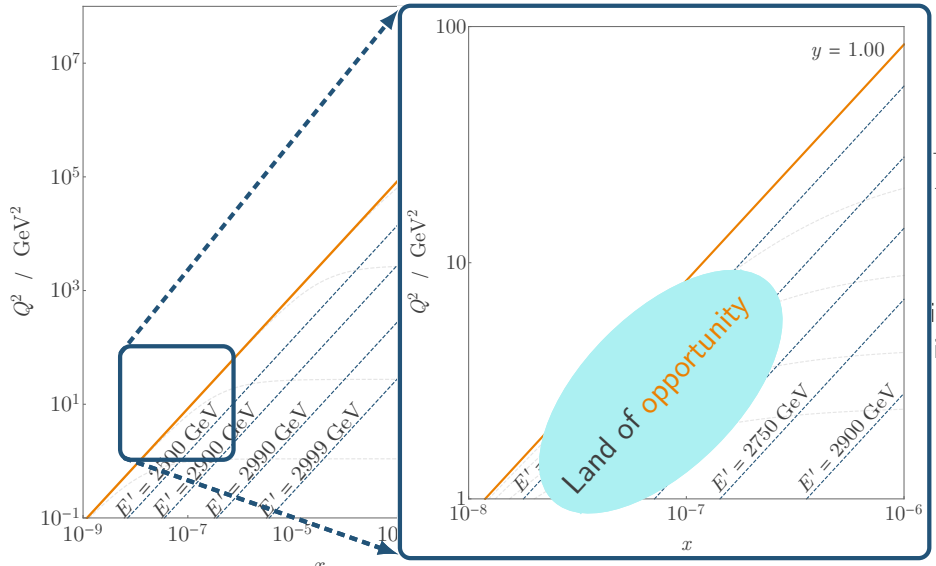

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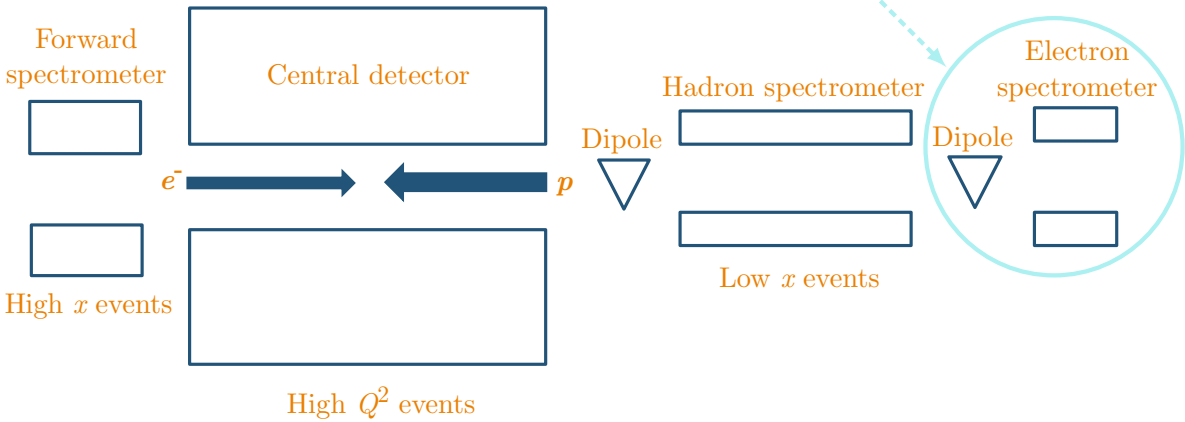
Large ΔE_e allows separation of scattered electrons.



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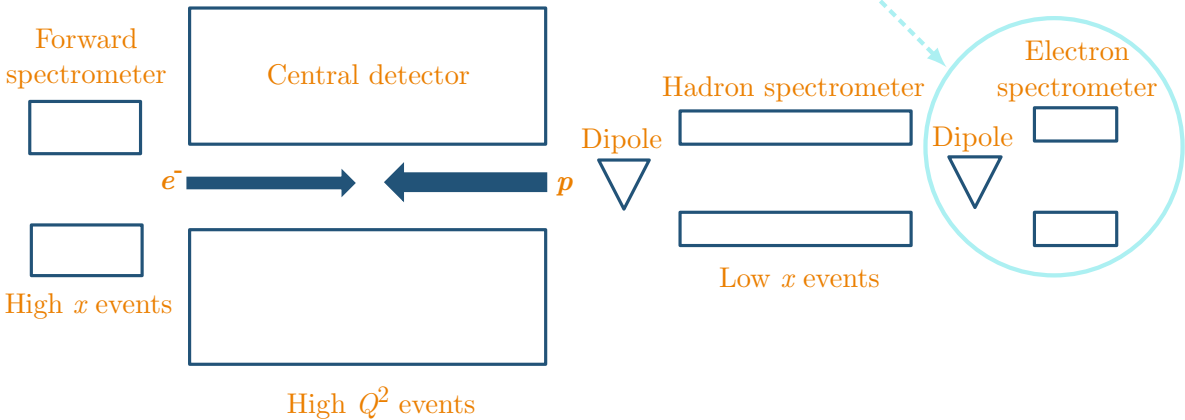
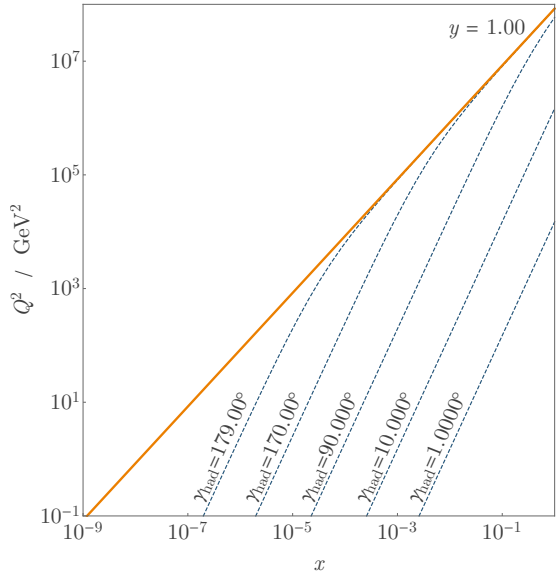
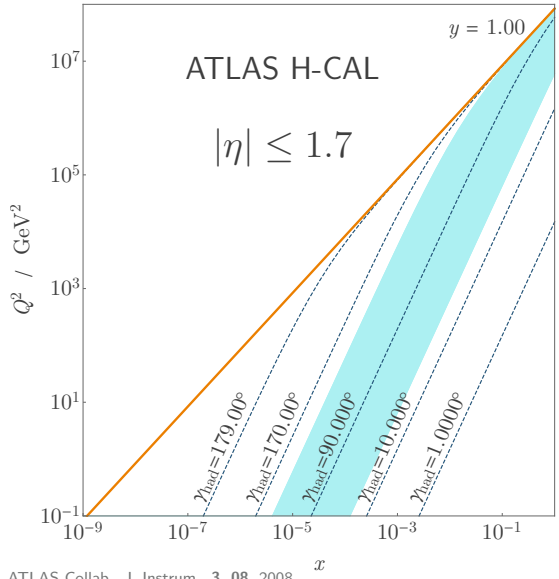


What about the hadronic final state?



$$Q^2(x,\, \gamma_{\text{had}}) = sx \cdot \frac{xE_p}{xE_p + E_e \cot^2(\gamma_{\text{had}}/2)}$$

- Post-collision **hadrons** in the region of interest will be collinear or near-collinear with the **electron** beam.



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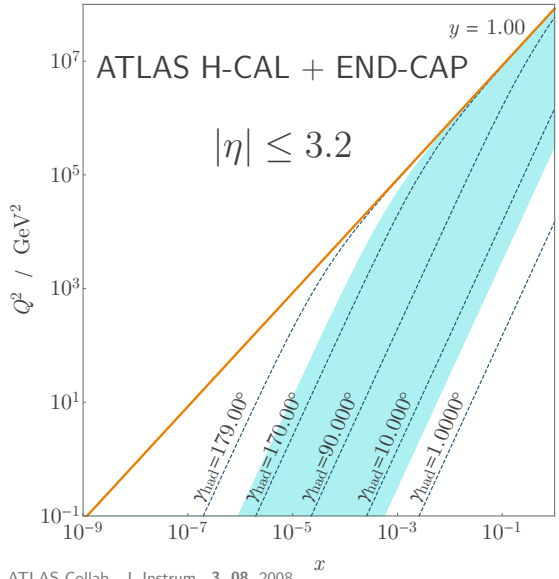
ATLAS Collab., J. Instrum., **3, 08**, 2008



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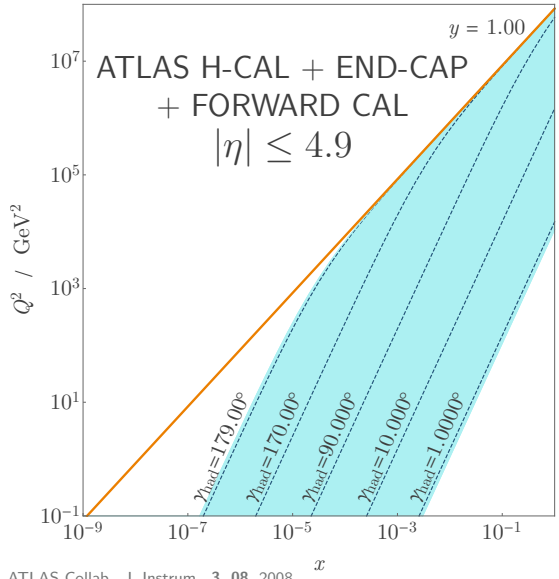

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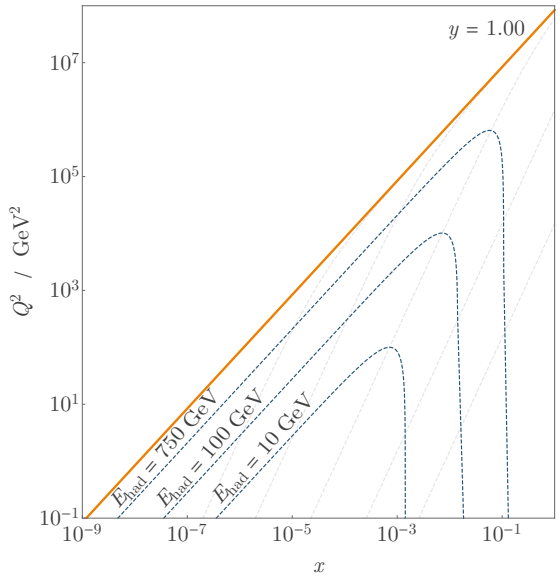
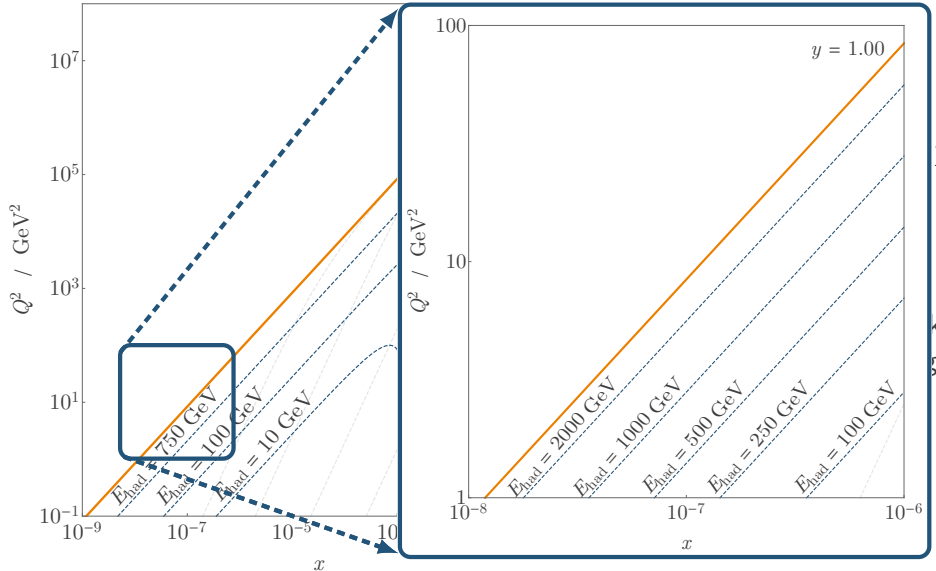


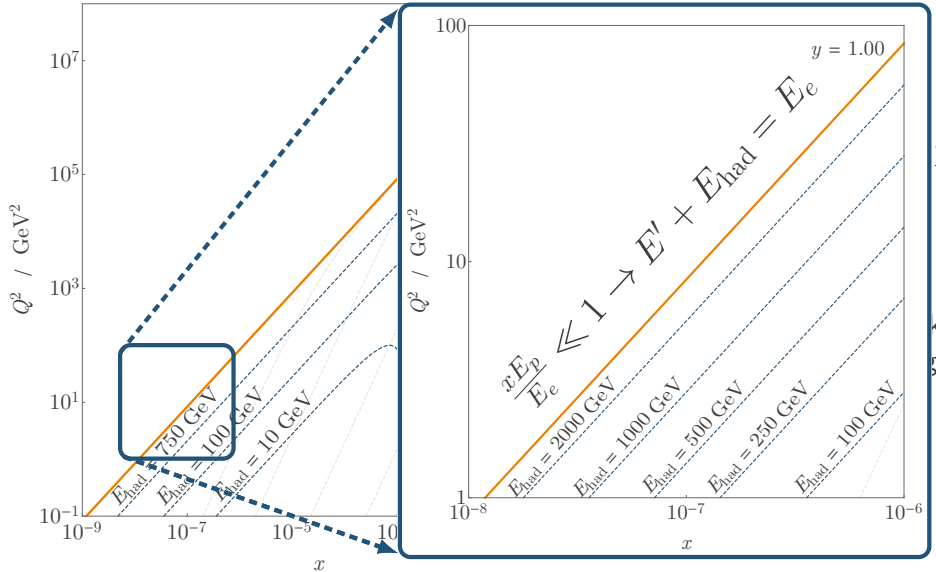
$$Q^2(x,\, E_{\text{had}}) = sx \cdot \frac{xE_p - E_{\text{had}}}{xE_p - E_e}$$

- Post-collision, the struck parton can be very energetic in the region of interest.



$$\frac{xE_p - E_{\rm had}}{xE_p - E_e}$$

k parton can be
gion of interest.



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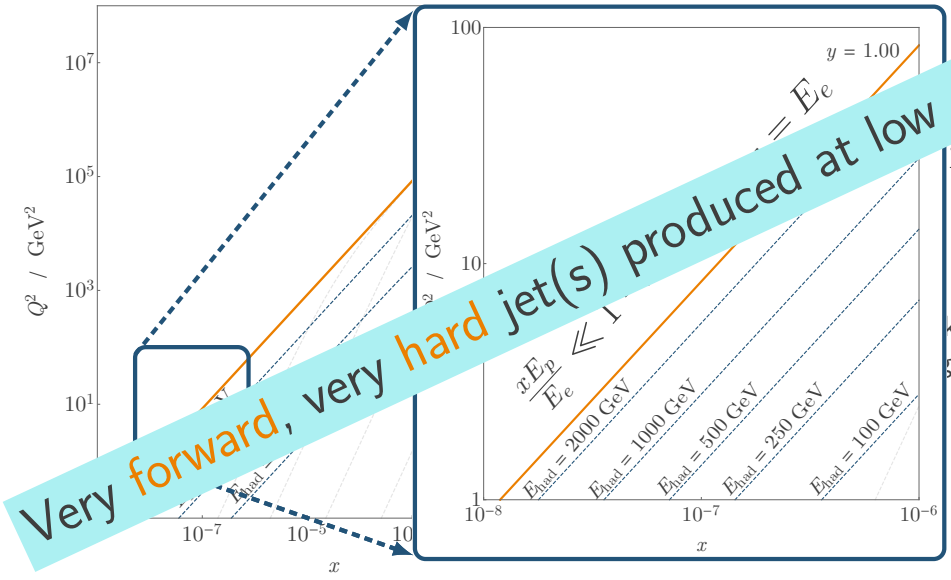

$$\frac{xE_p - E_{\mathrm{had}}}{xE_p - E_e}$$

k parton can be
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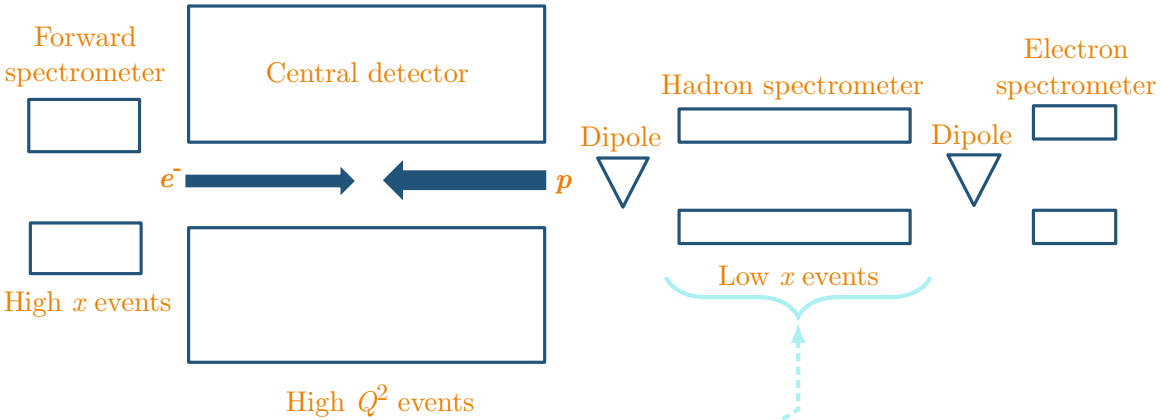
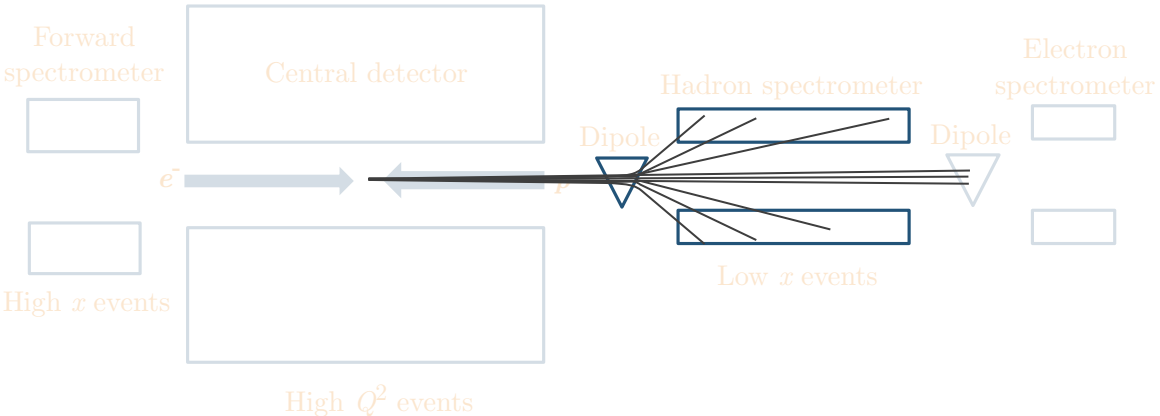
Very forward, very hard jet(s) produced at low x and Q^2.



Is this the right choice for a boosted high energy jet?

Straw man jet



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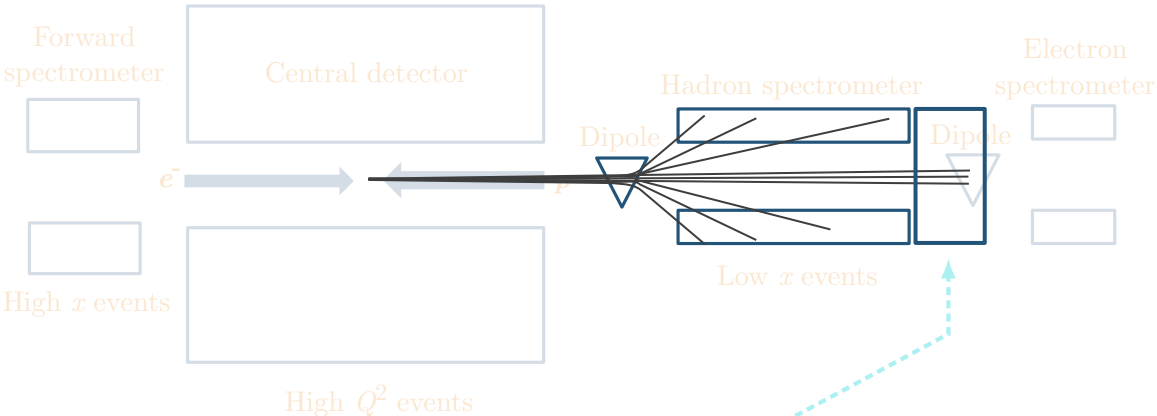
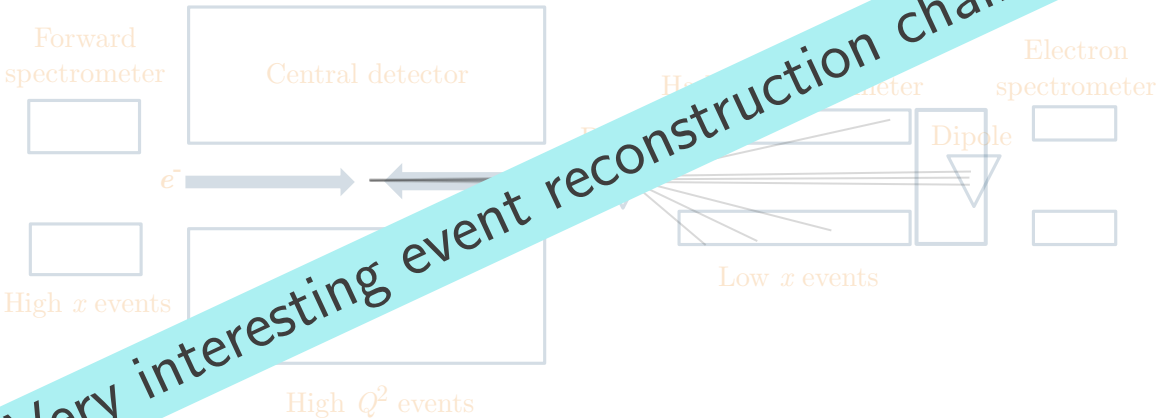
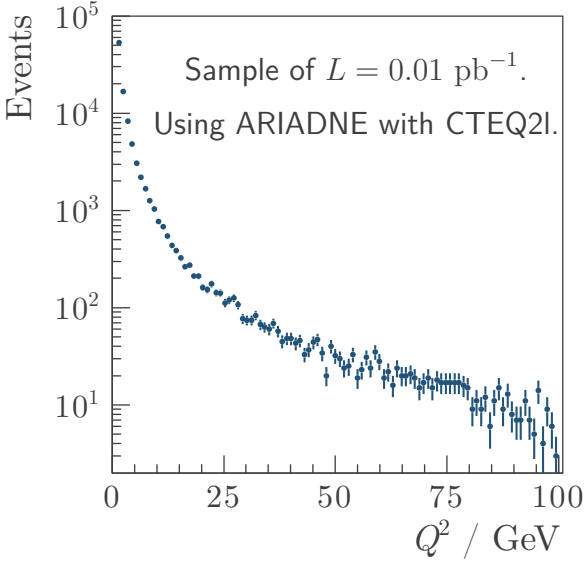


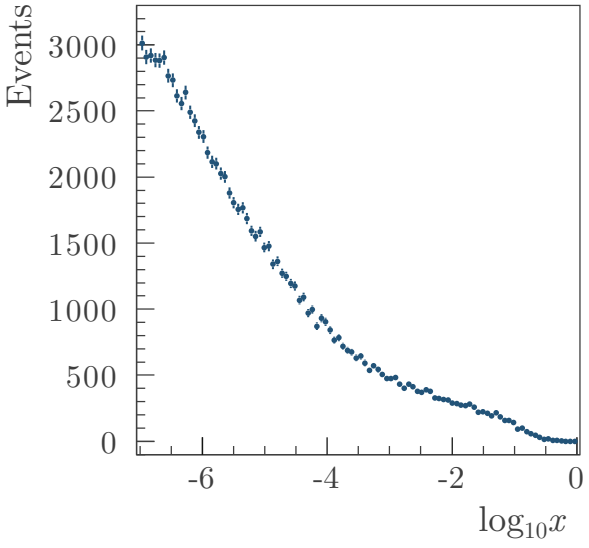
Zero degree calorimeter needed for neutral hadrons.

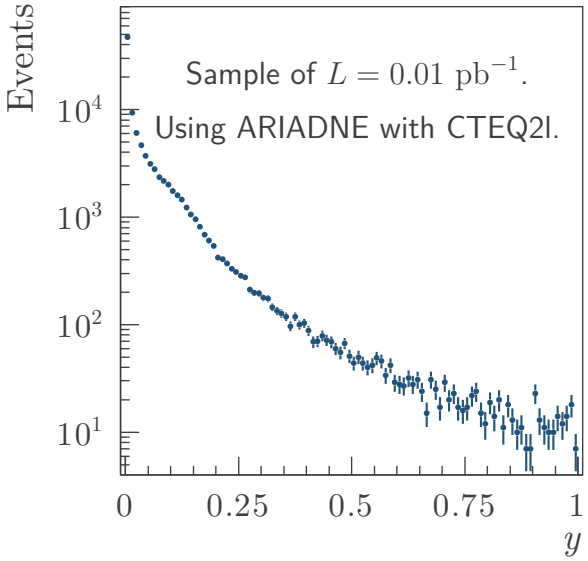


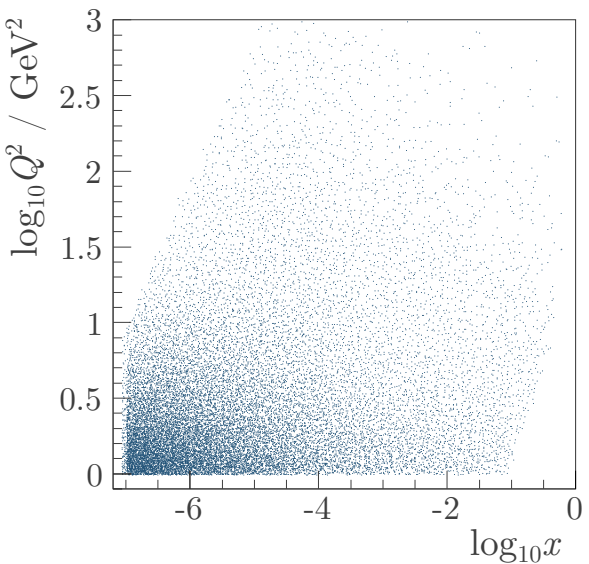
Very interesting event reconstruction challenge.

VHEeP MC

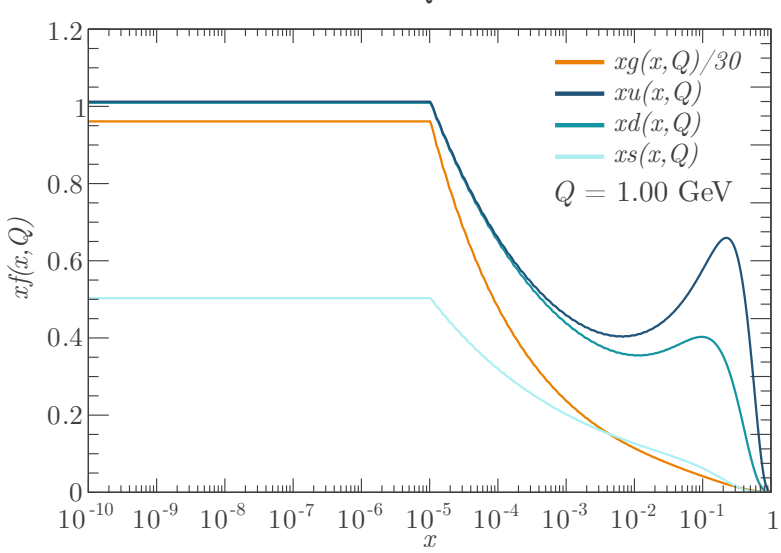

Events
10^5
10^4
10^3
10^2
10^1
Sample of $L = 0.01$ pb^{-1}.
Using ARIADNE with CTEQ2l.
0
25
50
75
100
Q^2 / GeV


Events
3000
2500
2000
1500
1000
500
0
-6
-4
-2
0
$\log_{10}x$

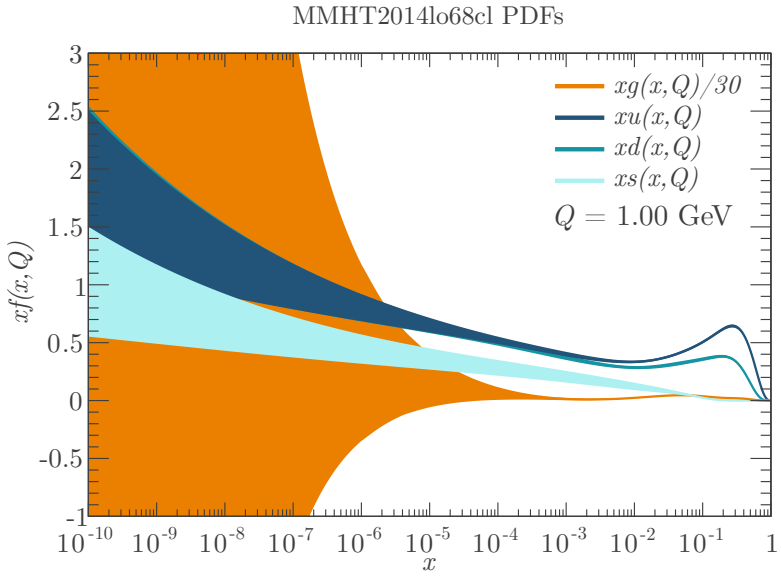

Events
Sample of $L = 0.01$ pb^{-1}.
Using ARIADNE with CTEQ2l.
10^4
10^3
10^2
10^1
0
0.25
0.5
0.75
1
y


$\log_{10} Q^2$ / GeV^2
3
2.5
2
1.5
1
0.5
0
-6
-4
-2
0
$\log_{10} x$

- CTEQ2l was not available as an LHAPDF file but we can look at CTEQ4l and hope they are similar.
- Suggests that the low x weighting of Matthew and Allen's results was not high enough.
- Can we do better with more modern PDFs and more modern generators?



- As a UCL student, my first instinct is to look at MMHT2014.
- The bands correspond to Hessian 68% CLs.
- Below the data the line is extrapolated linearly in $\ln(xf(x,Q))$ so ends up looking like a power law on this log-linear plot (CTEQ do the same now).
- The uncertainty is very large in the region of interest.



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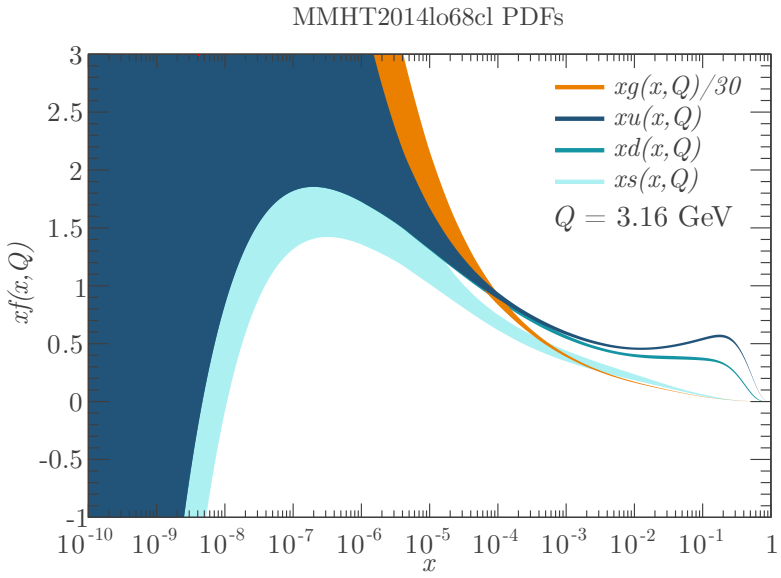

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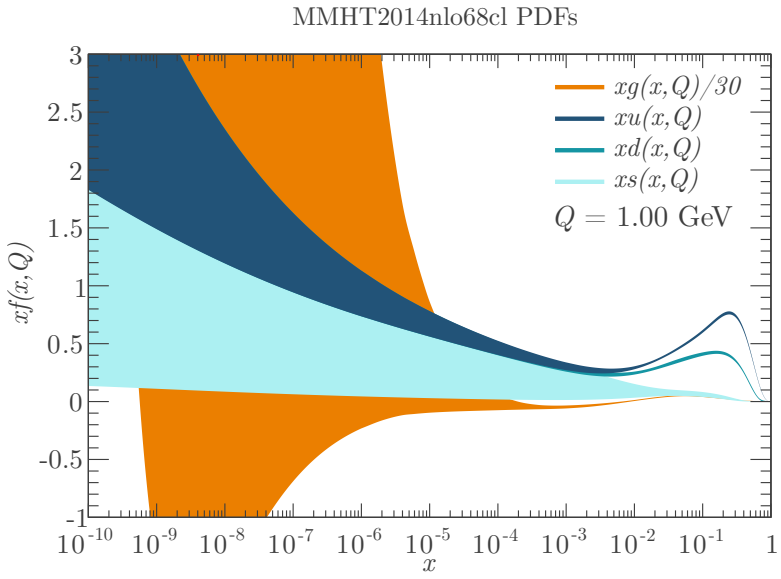

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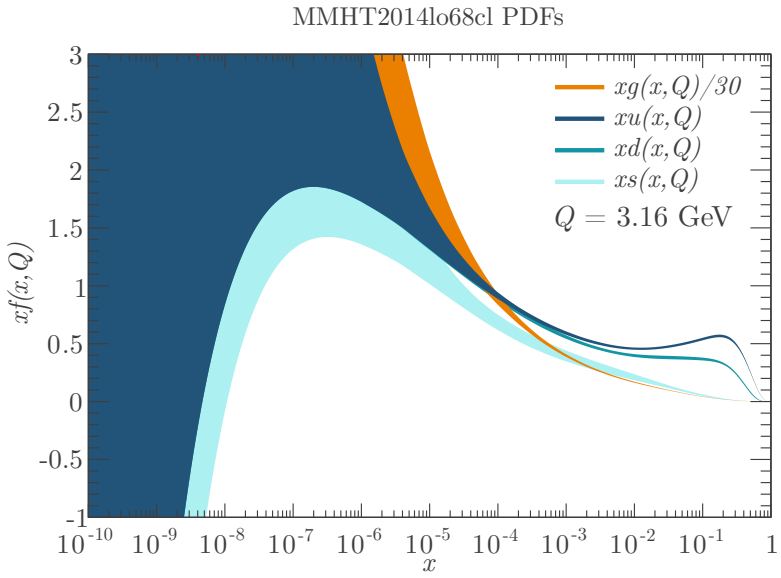

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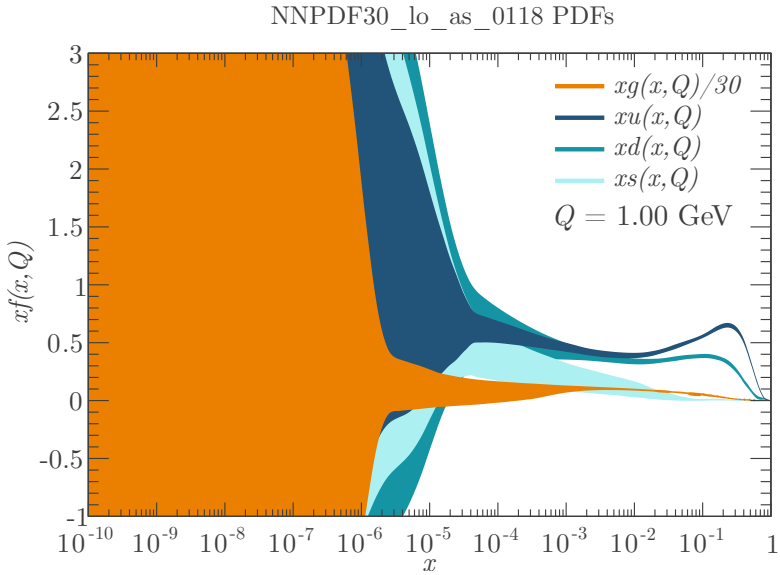
- NNPDF 3.0 uses a different error calculation (MC sampling of the neural nets) which gives a much wider band.
- Particularly high probability of negatively weighted events using this PDF, even at LO.
- I will come back to this very shortly.



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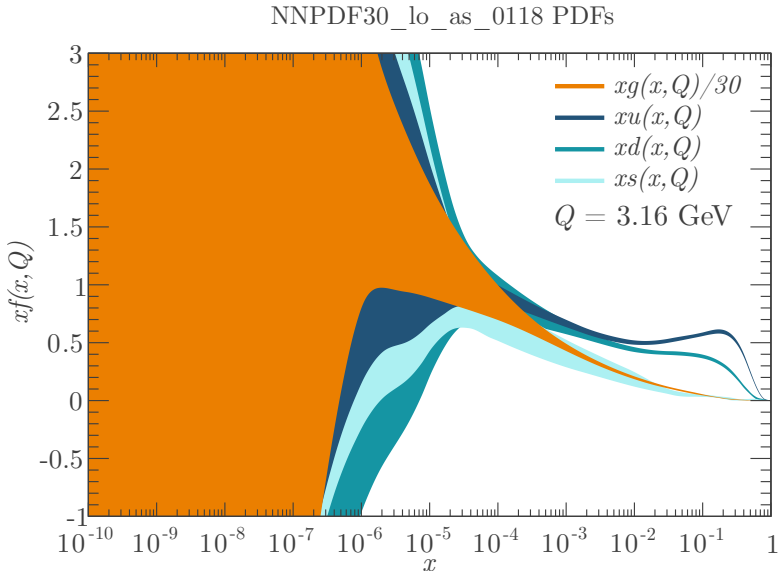

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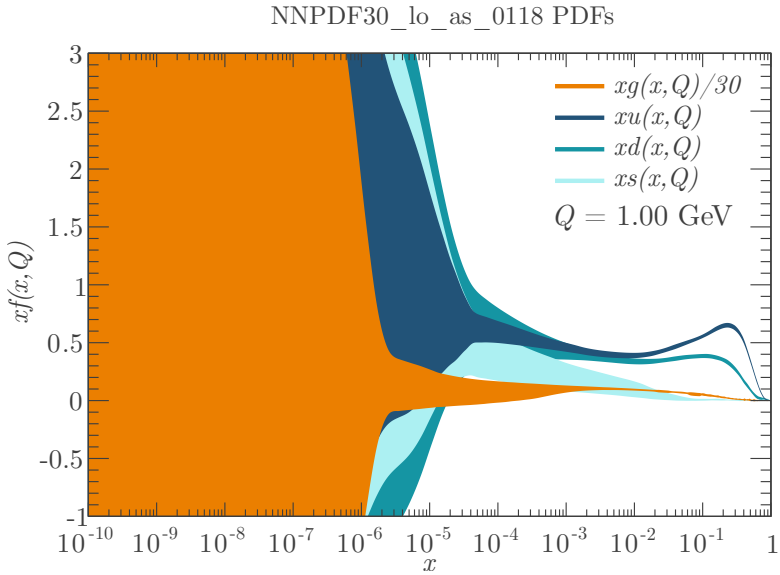

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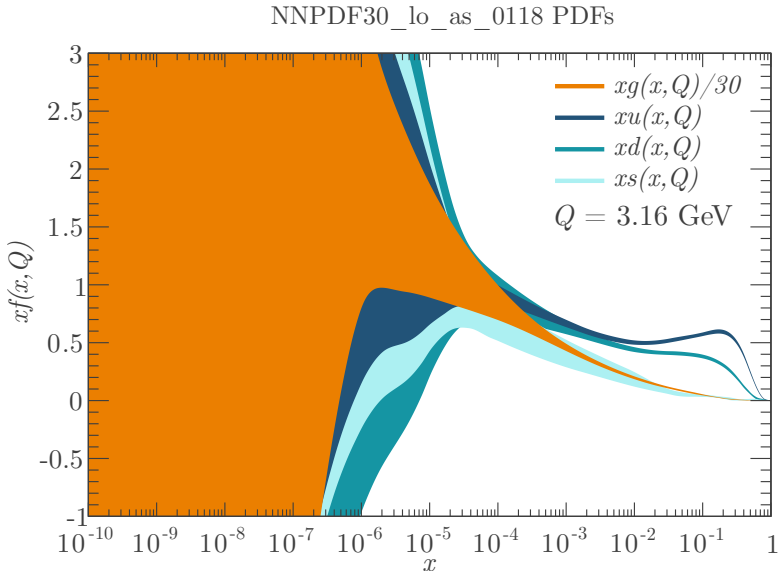
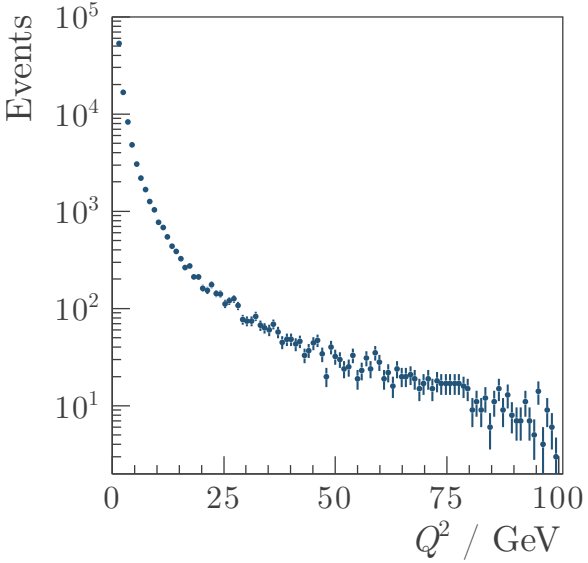
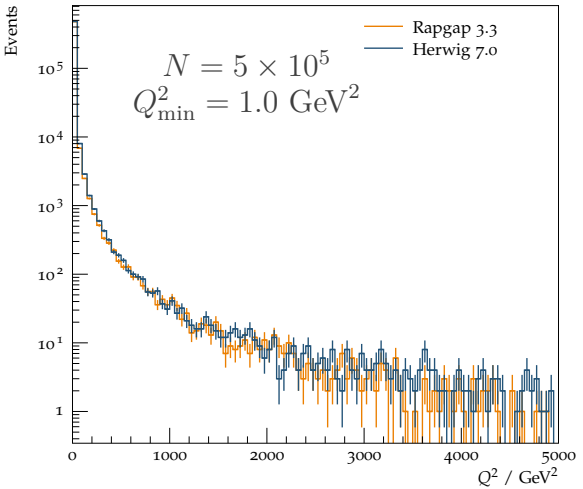


Concrete progress on VHEeP MC

- With the help of a masters student (Emma Simpson Dore, now bound for KIT) we've entered the 21st century.
- We have the Rapgap 3.3 running with the Rivet toolkit.
  - We've benchmarked our version of this against a H1 analysis.
  - We've managed to get it working with some of the modern PDFs (NNPDF3.0 and CT14 work, MMHT2014 doesn't yet).
- We've made a Rivet routine to assess the final state for the VHEeP kinematics.
  - This is a very general routine looking at x, Q^2, y, θ_e, γ_{had}, etc.
- We've also got Herwig 7.0 working for DIS with the VHEeP rivet routine.
  - This is particularly good as it is truly a modern event generator.
  - Some mysteries about low x PDF treatment, however.
- We've also being working on running Rapgap in diffractive mode to simulate exclusive photoproduction of J/ψ mesons.
  - We're trying to replicate another H1 analysis.
  - With help from Hannes, this is moving forward - slowly.

Using NNPDF 3.0 LO $\alpha_s(M_z) = 0.118$





Plots made using Rivet: arXiv:1003.0694

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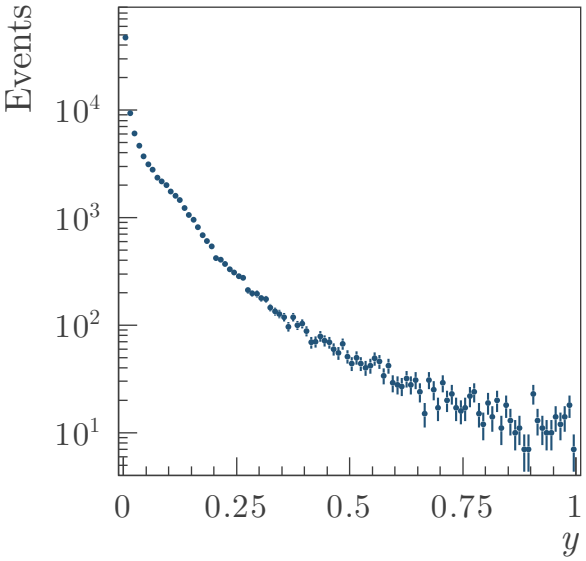
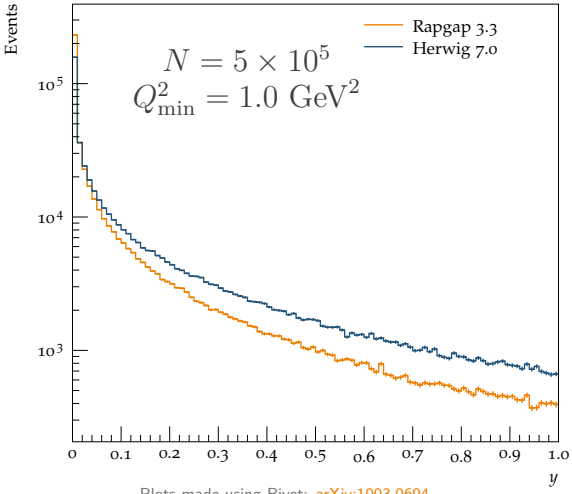


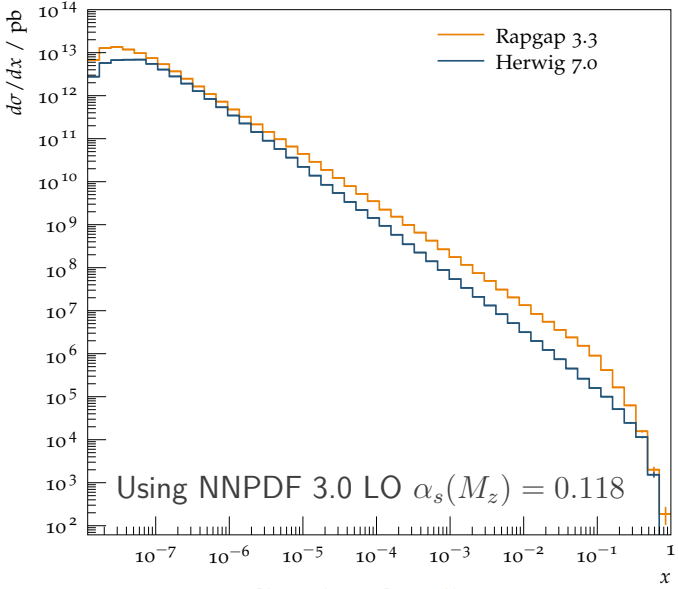


Plots made using Rivet: arXiv:1003.0694

PDF Uncertainties - A cautionary tale

UCL

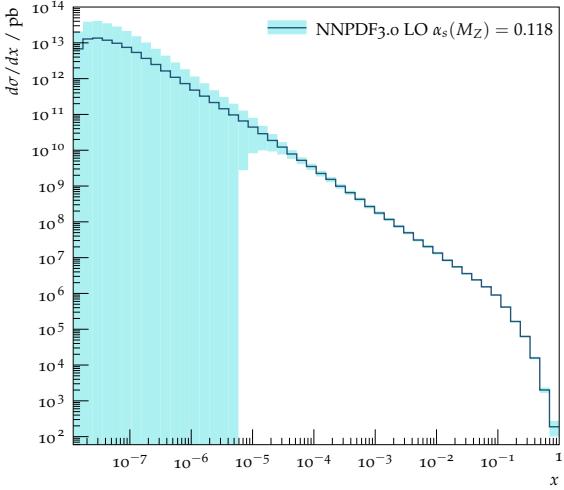
- To make this more concrete, consider $d\sigma/dx$ rather than the number of events.
- We can apply a *post hoc* reweighting of these events using LHAPDF to take the PDF uncertainty into account*.



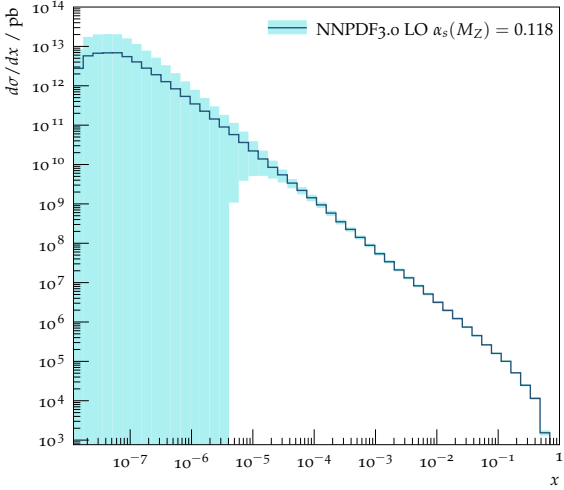
*Thanks to David Yallup for his help with this.

Plots made using Rivet: arXiv:1003.0694

Rapgap



Herwig



Plots made using Rivet (arXiv:1003.0694) and LHAPDF (Eur.Phys.J. C75 (2015) 3, 132)

Conclusions

As we have heard throughout this workshop, very high energy eP and eA physics is a much richer field than the LO pQCD eP DIS I have just discussed. Nevertheless, we can draw conclusions from this case.

- The final state will be very challenging to measure but not impossible.
  - A very flexible system is required to deal well with the electron and jet final state.
  - This is particularly true if either of the beam energies will be varied.
- PDFs in the VHEeP region are unconstrained by data and follow questionably motivated extrapolations with equally questionable uncertainties.
  - This collider could change that - with potentially widespread benefit.
- Modern event generators are available for eP physics.
  - Due to the large PDF uncertainties I cannot recommend using inclusive eP predictions as support for the collider.
  - Hopefully, I have shown that you can go a long way to understanding the technical challenge without using MC.